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16. Abstract

A study was conducted on a closed track in both daytime and nighttime conditions to compare the conspicuity of three different types of safety garment for use by first responders; NFPA 1971 turnout gear coats, and ANSI/ISEA 107 and 207 safety vests. Eight participants, balanced for gender and age, drove instrumented vehicles on the closed track indicating the distance at which they could detect pedestrians in a simulated emergency response scene. Pedestrians, wearing one of the safety garments, stood adjacent to the emergency scene, on either the right or the left side, oriented either facing or perpendicular to oncoming traffic. The effect of pedestrian motion on detection was also examined by having pedestrians stationary or walking in place.

The results show that there was no statistically significant difference in the distance at which pedestrians were detected, regardless of which garment was worn. In other words, all three standards of garment provided equal levels of conspicuity under the conditions examined. Time of day was a significant factor, with mean detection distances being longer during the daytime for all garments. Pedestrian orientation was significant, with mean detection distances being longest when facing traffic, but pedestrian motion did not result in significant differences in detection distance. The results suggest that all of the garments studied should be considered equivalent relative to making first responders conspicuous when working in close proximity to traffic.

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INTRODUCTION

Problem: Pedestrian Fatalities Due to a Lack of Conspicuity

In 2005, 4,881 pedestrians were killed in traffic crashes in the U.S. (U.S. DOT, 2005). Enhancing the conspicuity of pedestrians so that approaching motorists are able to detect, recognize, and respond is vital in reducing pedestrian fatalities. In an attempt to reduce pedestrian traffic fatalities and injuries, the Federal Highway Administration (FHWA) recently enacted new rulemaking that requires the use of high-visibility safety apparel for all workers present within the rights-of-way of federal-aid highways (Federal Register, Vol. 71, No. 226, November 24, 2006 – effective date November 24, 2008). These pedestrians are exposed directly to traffic (e.g., surveyors) or to equipment present in a work zone (e.g., road construction workers). The new rulemaking explicitly references ANSI/ISEA 107-2004 in determining whether a garment satisfies the new FHWA requirement for high-visibility safety. Pedestrians in many occupations beyond surveying or road construction are also frequently in close proximity to moving traffic on roadways, and this rulemaking applies to all of them. Examples of such occupations are emergency services, including fire fighting, law enforcement, and emergency medical care. Workers involved in these occupations are often the first to respond to a crash, or other form of emergency on our nation's highways, and as such, are referred to collectively as first responders. Yet for at least one of these occupations, firefighters, there already exists a common-practice standard for the inclusion of high visibility materials into the design of their safety garments—referred to as turnout gear—the design of which is not explicitly consistent with ANSI/ISEA 107-2004, but which is compatible with the heat and flame hazards.

As with the high-visibility safety apparel outlined in ANSI/ISEA 107-2004, retroreflective and fluorescent materials are incorporated into turnout gear. For firefighters, these materials enhance their visibility on the road, and therefore promote their safety as pedestrians. The materials also aid in locating emergency personnel in a variety of hazardous scenarios off the road. The two separate standards, NFPA 1971-2007 and ANSI/ISEA 107-2004, each specify amounts of retroreflective material, fluorescent material, and the location/configuration of retroreflective material. However, in light of the FHWA rulemaking, an obvious question becomes whether safety garments such as those meeting NFPA 1971-2007 perform sufficiently for first responders to comply with the intent of SAFETEA-LU sec. 1402 by making the wearer at least as conspicuous as personnel wearing ANSI/ISEA 107-2004-compliant garments. Otherwise, under the proposed rulemaking, firefighters and other first responders to crashes on federal-aid highways will be required to wear ANSI/ISEA 107-2004-compliant garments over their existing apparel.

Policies and Standards for Safety Garments

23 CFR Part 634

The FHWA legislation, SAFETEA-LU 2005, included in sec. 1402 provides direction to the Secretary of Transportation to

> "…issue regulations to decrease the likelihood of worker injury and maintain the free flow of vehicular traffic by requiring workers whose duties place them on or in close proximity to the right of way of Federal-aid highway (as defined in section 101 of title 23, United States Code) to wear high visibility garments."

In November 2008, the policy 23 CFR part 634 will come into effect mandating that all pedestrians working within rights-of-way to federal-aid highways wear high-visibility safety garments, such as a retroreflective vest or other compliant apparel. The only named standard for high-visibility garments approved under the new rulemaking is ANSI/ISEA 107-2004. Specifically, the equivalent of a Class 2 or Class 3 garment is required. A companion standard, ANSI/ISEA 207-2006, was published after the new federal policy was adopted, and has been slated for incorporation into federal high-visibility regulations as an option in the 2009 draft of the MUTCD. Garments that are compliant with ANSI/ISEA 207-2006 have the same amount of retroreflective material as a Class 2 garment in ANSI/ISEA 107-2004, but may have reduced fluorescent background material.

ANSI/ISEA 107-2004

The American National Standards Institute and International Safety Equipment Association issued a revised standard for high-visibility safety apparel in 2004. Three classes of high-visibility safety apparel are outlined by the ANSI/ISEA 107-2004, and these are differentiated by the level of conspicuity considered necessary for the intended application in which the pedestrian is engaged. Class 2 safety apparel, for example, is intended to be worn by pedestrians working in close proximity to roadways where traffic exceeds 25 mph. The minimum width of the retroreflective material used on these garments should not be less than 35 mm and have a combined area of 0.13 m^2. Class 2 garments are also required to have a minimum area of 0.50 m^2 of visible fluorescent background material.

The combined-performance materials, those which are both retroreflective and fluorescent, on a Class 2 garment should not be less than 50 mm wide. Horizontal retroreflective materials that are placed near the bottom edge of a garment should not be placed less than 50 mm above the hem. The fluorescent yellow-green colored retroreflective background or combined-performance material should have a minimum total luminance factor (Y expressed as a percentage) of 76% or 70%, respectively.

ANSI/ISEA 207-2006

The American National Standards Institute and International Safety Equipment Association issued ANSI/ISEA 207-2006 as a companion standard to ANSI/ISEA 107-2004 to address the needs for high-visibility garments worn by public safety personnel, specifically law enforcement officers, who have tactical design requirements, such as a need for access to a duty belt, as part of their specific work environment. ANSI/ISEA 207 garments are to have a minimum of 0.29 m^2 of fluorescent background material and 0.13 m^2 of retroreflective material. The retroreflective material is required to be a minimum of 50 mm in width, and at least 50% of the retroreflective material should be contiguously distributed within the background material. Multiple bands should be spaced at least the distance equivalent to the width of the band. Retroreflective material should not be placed lower than 50 mm above the hem, and gaps should not be larger than 50 mm. There should be contiguous areas of retroreflective material encircling the torso, and vests should have one or more horizontal bands of retroreflective trim and a vertical band on each shoulder connecting the torso bands.

NFPA 1971

The NFPA 1971-2007 standard on protective ensembles, or turnout gear, for structural fire fighting requires safety ensembles to include permanently attached high-visibility materials. The trim is required to be at least 50 mm wide, with the retroreflective surface being 16 mm wide. The fluorescent and retroreflective trim needs to appear continuous from a distance of 30.5 m and have no gaps of more than 3 mm. The minimum trim pattern for a jacket includes a circumferential band of trim 50 mm above the hem. The front of the jacket should have at least one band of horizontal trim at the chest level. The back of the jacket should have a minimum of two vertical stripes of trim, one each on the left and right sides, perpendicular to the bottom band, or there can be a minimum of one horizontal band of trim at the chest/shoulder blade level. The minimum trim requirement for each sleeve includes a circumferential band between the wrist and elbow level. NFPA 1971 also requires garment trim to have a coefficient of retroreflection not less than 100 cd/lux/m^2, and it must pass thermal testing for high heat and flame hazards.

Relevant Studies

Johansson (1973) was the first to demonstrate that certain human movements (walking, running, etc.) are comprised of a series of pendular motions which form patterns that can readily be identified as a human in motion when main joints of the human body are highlighted. These patterns were termed biological motion by Johansson.

Bloomberg, Hale, and Preusser (1986) performed a test-track experiment examining the placement of retroreflective markings, along with some active light sources. The authors reported that every retroreflective marking or luminary treatment condition examined resulted in significantly longer detection distances relative to a pedestrian wearing only blue jeans and a white T-shirt. However, recognition distances were not significantly improved by the application of retroreflective dangle tags.

While a number of studies have demonstrated the general effectiveness of retroreflective markings and garments (see Moberly and Langham (2002) for a review), Owens, Antonoff, and Francis (1994) were the first to test the possible effects of Johansson's biological motion phenomenon. Owens et al. tested whether marking all major joints on a pedestrian would increase recognition distance when compared to retroreflectors placed on other locations of the body (e.g., the torso). Subjects viewed video tapes of a jogger wearing four different retroreflector configurations. Their task was to respond as quickly as possible when they saw the jogger. The results showed that subjects responded sooner to the biological motion condition compared to markings on the torso. However, the evidence to support an effect of biological motion is inconclusive. Kwan and Mapstone (2004) did a meta-analysis reviewing studies looking at pedestrian visibility aids and found that the use of visibility aids at night increases detection distances, while the placement of retroreflectors on the body's major joints producing biological motion does not provide further benefit.

Luoma, Schumann, and Traube (1995) conducted a field study in which they examined how retroreflector placement affects pedestrian conspicuity on actual roadways. Participants performed a recognition task while seated in a passenger car driven by a researcher at a constant speed. The authors examined the placement of retroreflectors in three positions (on the shoulders and around the torso, on the wrists and ankles, and stripes placed around major joints) as well as a dark-clad condition. Recognition distances were greatest when the retroreflective markings were placed on the major joints—closely followed by placement on the wrists and ankles. In a follow-up study, Luoma and Penttinen (1998) examined the differences between the mean detection distances of the previous study performed with participants in the United States (Michigan) and Finnish participants. The results were similar, with the wrist and ankle configuration having the greatest recognition distance followed by the major joints, and torso and shoulder configurations.

In a field study involving nighttime pedestrian visibility, Wood, Tyrrell, and Carberry (2003) compared a retroreflective vest, a biological motion condition, white clothing, and black clothing for conspicuity. They found that the biological motion condition yielded the highest recognition distances, followed by the retroreflective vest.

However, the retroreflective vest tested did not provide significant differences in recognition distance compared to a pedestrian wearing white clothing.

In a study concerning high visibility safety apparel and nighttime pedestrian conspicuity, Sayer and Mefford (2003) compared three ANSI 107 compliant garments: a Class 2 vest, a Class 3 vest, and a Class 3 jacket. They found the Class 3 jacket was the most conspicuous, possibly as a result of the retroreflective bands on the arms creating a biological motion effect when the pedestrian was moving.

Sayer and Mefford (2004) examined the roles of retroreflective arm treatments in stationary and moving pedestrians in differing orientations and scene complexities. Results showed that motion increased detection distances significantly, which may have been because it resulted in a "flashing" appearance of the arms moving across the torso trim. When pedestrians were perpendicular to traffic, the detection distances of moving pedestrians greatly increased compared to that of pedestrians facing traffic.

Lastly, in another study of conspicuity of high-visibility safety garments, Sayer and Mefford (2006) reported that mean detection distances were longer for a retroreflective-trimmed jacket than a vest, and that arm motion increased detection distances for both the jacket and vest conditions.

The Present Study

The objective in the present study is to compare garments that are consistent with the recent FHWA rulemaking (ANSI/ISEA 107-2004 compliant) with those compliant with the future 2009 MUTCD regulation (ANSI/ISEA 207-2006 compliant), and those intended to serve firefighters (NFPA 1971-2007 compliant) to determine if one type of garment makes pedestrians more conspicuous. The measure of conspicuity examined in the present study is the distance at which a pedestrian can be detected in a visual search task conducted in a simulated emergency scene. This research examines both daytime and nighttime conditions because of the different visibility issues under those conditions. In addition, this study was designed to further our understanding of the contribution of biological motion to pedestrian conspicuity for garments meeting each of the three standards.

METHOD

Participants

Eight licensed drivers participated in this study. Each participant was paid $75 for taking part in a single three-and-a-half hour session. Driver age was a two-level independent variable, composed of four older participants (63 to 67 years, mean = 65) and four younger participants (22 to 28 years, mean = 24). Each age group was balanced for gender. All participants were recruited from a database of individuals who have participated in previous UMTRI studies, but had not recently taken part in related studies on pedestrian conspicuity. All participants had normal color vision as determined by using pseudoisochromatic plates (Ichikawa, Hukami, Tanabe, and Kawakami, 1978) and visual acuity of 20/40 or better.

Materials

Garments

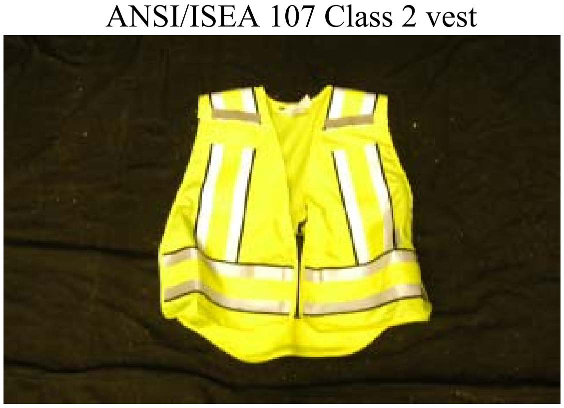
Four garments were tested for daytime and nighttime conspicuity: two ANSI/ISEA-compliant vests and two firefighter jackets (turnout gear). Details about these garments are provided in Table 1, while images of the garments are provided in Figure 1. All garments used in this study were new and had not been laundered, and as such were in optimal condition. One garment was an ANSI/ISEA 107-2004-compliant Class 2 vest having one horizontal band of 50 mm retroreflective trim around the torso and two vertical bands over the shoulders. A second vest, an ANSI/ISEA 207-2006-compliant garment, had combination trim around the torso and two vertical bands of combination trim over the shoulders. Both vests had fluorescent yellow-green background material with silver retroreflective trim. The firefighter turnout gear was compliant with NFPA 1971 and used the standard New York Fire Department pattern of combination trim with two horizontal bands around the torso and two bands on each arm. The jacket was tested with two different background colors (black and gold), but both had identical yellow-green and silver combination trim.

Table 1
Garment specifications.

Garment	Background Color	Trim Color	Fluorescent Material (m^2)	Retroreflective Material (m^2)
NFPA 1971 Turnout Gear	Black	Fl yellow-green & silver	0.3	0.13
NFPA 1971 Turnout Gear	Gold	Fl yellow-green & silver	0.3	0.13
ANSI/ISEA 107 Class 2 vest	Fl yellow-green	Silver	0.9	0.14
ANSI/ISEA 207 Class 2 vest	Fl yellow-green	Silver	0.7	0.17


ANSI/ISEA 107 Class 2 vest


NFPA 1971 Turnout gear (black)


ANSI/ISEA 207 Class 2 vest


NFPA 1971 Turnout gear (gold)

Figure 1. Garments used as stimuli.

Simulated Emergency Response Scene

The study was performed using the Vehicle Dynamics Facility at the Chrysler Proving Grounds in Chelsea, Michigan. The track configuration is a 4.43-km oval, with straightaways of 1.55 km and a 10-acre skid pad. This is a closed-track test facility with an asphalt surface two lanes wide. The track has non-reflective lane delineators and no fixed lighting. Other than the existence of guardrails in the turns, there are no fixed, rigid structures within 25 m of the track surface. Areas adjacent to the track are largely grass covered and flat, although some adjacent areas are asphalt surfaces, primarily in the vicinity of the skid pad. Two identical mock emergency scenes were simulated on the track. Both mock scenes were located on the right side of the roadway, on opposite sides of an oval (2.21 km of track separation).

The scenes included the simulation of the rear of a fire truck and the positioning of a single emergency responder (Appendix). The simulated rear of the fire truck was 2.8 m tall and 2.5 m wide (Figure 2). The simulated fire trucks were constructed of plywood that was painted red, silver diamond plate sheeting, and red and orange chevron retroreflective sheeting. Each simulated truck included a set of red Whelen 900 series Smart LED lights on the top, a set of red 700 series Smart LED lights, and red 600 series brake/tail/turn lights at the bottom. All were operational and remained steadily lit or flashing during the study. The simulated truck also included a flashing, eight-LED traffic advisor light bar that was operational during testing.

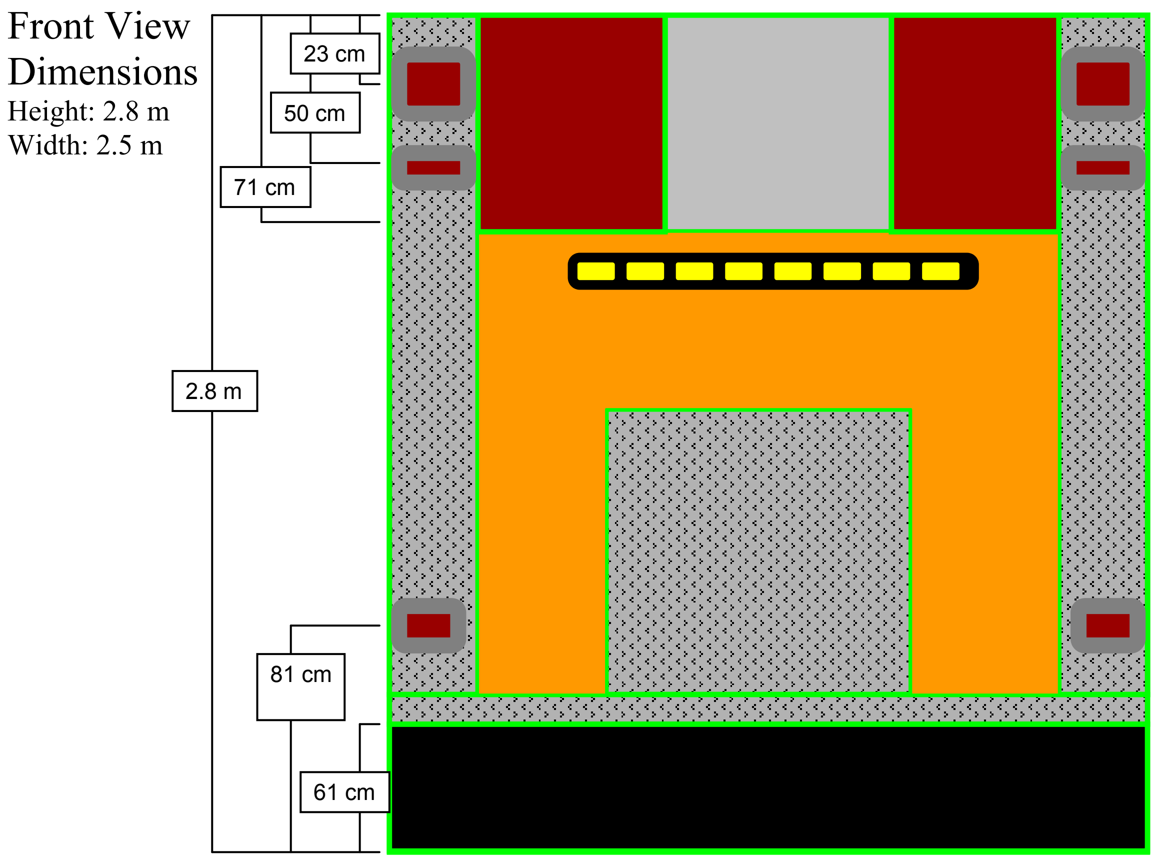


Figure 2. Simulated fire truck specifications.

Test Vehicles

Two 2003 Nissan Altimas with automatic transmissions were used as test vehicles. Each vehicle included a forward-looking camera, a self-illuminated IR camera mounted in the A-pillar and aimed at the driver's face, and an UMTRI-designed data acquisition system collecting a variety of vehicle and driver performance variables at 10 Hz from the vehicle's controller-area network (CAN) bus. The data acquisition systems included a differential global positioning system, a computer with hard disk, and a button for "tagging" the vehicle performance data to indicate the location at which participants first detected pedestrians located in the mock emergency scenes.

Two main types of data were collected from the vehicles in this study: driver performance data and vehicle location on the track. The driver performance data provided information about the driver's input to the vehicle. The channels of vehicle performance data were selected to encompass all forms of driver input (steering wheel, brake, and accelerator pedal) and vehicle position and orientation were selected to determine the distances at which pedestrians were first detected. The vehicle performance data channels collected in this study, and their corresponding descriptions and units, are shown in Table 2.

The test vehicles had low-beam headlights turned on for the duration of the nighttime testing, and turned off during daytime testing. Proper headlamp aim was established before the start of the study, and the windshields and headlamps of the vehicles were cleaned regularly. Detection distance, the distance between the vehicle and the pedestrian when the participant first detected the pedestrian, was the dependent variable. Detection distance was determined by speed-integrated global positioning data.

Table 2
Vehicle performance data channels.

Name	Description	Units
Time	Time in centi-seconds since DAS application launch	csec
AccelPedal	Accelerator Pedal Position	unit less
Brake	Brake switch active	unit less
Speed	Vehicle Speed	m/sec
YawRate	Yaw Rate	deg/sec
Latitude	Latitude from DGPS	deg
Longitude	Longitude from DGPS	deg
GpsHeading	Heading - DGPS	deg
GpsNew	New DGPS data this sequence	deg
GpsSpeed	Speed from DGPS	m/sec

Pedestrians

Pedestrians stood in the mock emergency scene, either to the left or to the right of the simulated fire truck. On each trial, pedestrians wore one of the four safety garments while moving in place, with their arms swinging back and forth to simulate walking.

Lateral distance of pedestrians from the emergency vehicle was approximately three feet. Pedestrians could either be facing the simulated fire truck or facing oncoming traffic for each position (left or right) and safety garment condition. All conditions were counterbalanced using quarter fraction generators and randomized. Catch trials, where no pedestrian was present, were also included in the experimental design.

Procedure

After participants completed consent forms, their visual acuity and color vision were tested. Participants were told that the purpose of this study was to investigate the conspicuity of different safety garment for first responders. They were told that different garments would be worn by pedestrians standing to either the right or left of the simulated fire trucks. They were also told that some catch trials might be present. Participants drove the instrumented vehicle around the track in both daytime and nighttime conditions. The daytime portion of the testing took approximately one hour to complete and occurred in the evening before sunset. In between daytime and nighttime sessions, participants had a one hour break before lighting conditions were sufficiently dark to conduct the nighttime testing. Nighttime sessions took about one hour to complete and occurred after sunset.

For all laps around the test track, participants indicated the location at which they could first correctly identify the location of the pedestrians by saying "firefighter" aloud to a researcher riding in the backseat of the research vehicle. The researcher then pressed and held a response button, releasing it only when the vehicle reached the location of the pedestrian. The emergency scene was always on the right side of the two-lane track. Two people participated in the experiment at the same time, in different vehicles, on opposite sides of the track, traveling in the same direction. Participants were instructed to maintain a constant speed of about 35 mph during testing. Speeds were adjusted slightly so that the two vehicles did not come in close proximity to one another.

RESULTS

Statistical Analyses

The data were analyzed using a linear mixed-effects model. The within-subjects factors were safety garment (four levels), pedestrian location (two levels), pedestrian orientation (two levels), time of day (two levels) and trial repetition (each participant experienced each combination of the independent variables two times). The between-subjects factors were age (two levels) and gender (two levels). The dependent measure was the distance at which the pedestrian was first detected. Trial repetition was treated as a repeated measure (random effect), and was included in the model to determine whether there was a significant effect of learning. All other variables were entered into the model as fixed effects. Catch trials were not included in the analyses. The model was progressively improved by removing insignificant effects and then refitting the model. Except for presenting the result for the primary variable of interest, garment type, only statistically significant results will be reported.

Missed Trials

On the first day of testing, two subjects had missing data. In one instance, there was a missed button press indicating the position of the pedestrian. No value was entered for this trial. Six trials were run incorrectly. In four of those trials, the pedestrian was in the wrong position and in the other two trials, an incorrect garment was worn. For these six trials, the detection distance data were entered to correspond with the actual conditions presented and not the conditions that had been planned.

Main Effects

Garment Type

The effect of garment type was not statistically significant, $F(3, 444.4) < 1$.

Time of Day

The effect of time of day was statistically significant, $F(1, 7.1) = 132.7$, $p < .001$. On average, participants saw pedestrians in the daytime 495 m farther than pedestrians at night (Figure 3).

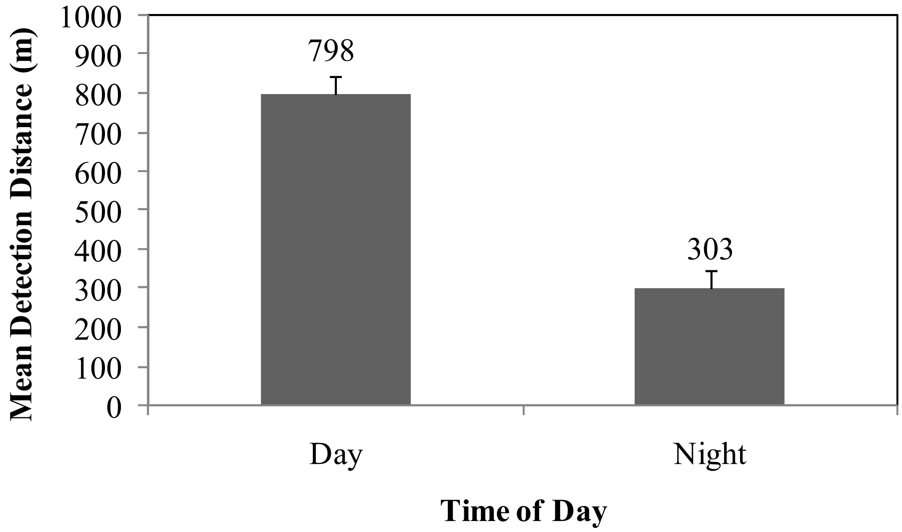


Figure 3. Mean detection distances for time of day. Error bars represent standard error of the mean.

Orientation

The effect of pedestrian orientation was statistically significant, $F(1, 443.3) = 16.7$, $p < .001$. On average, participants detected pedestrians who were facing oncoming traffic at longer distances than pedestrians perpendicular to oncoming traffic (582 m versus 519 m, respectively) (Figure 4).

Two-Way Interactions

Age by Position

The two-way interaction of participant age by pedestrian position was statistically significant, $F(1,15.8) = 7.0$, $p = .039$. Younger drivers detected pedestrians at substantially longer distances when they were standing to the left side of the scene, while older drivers detected pedestrians at farther distances when they were standing to the right side (Figure 5).

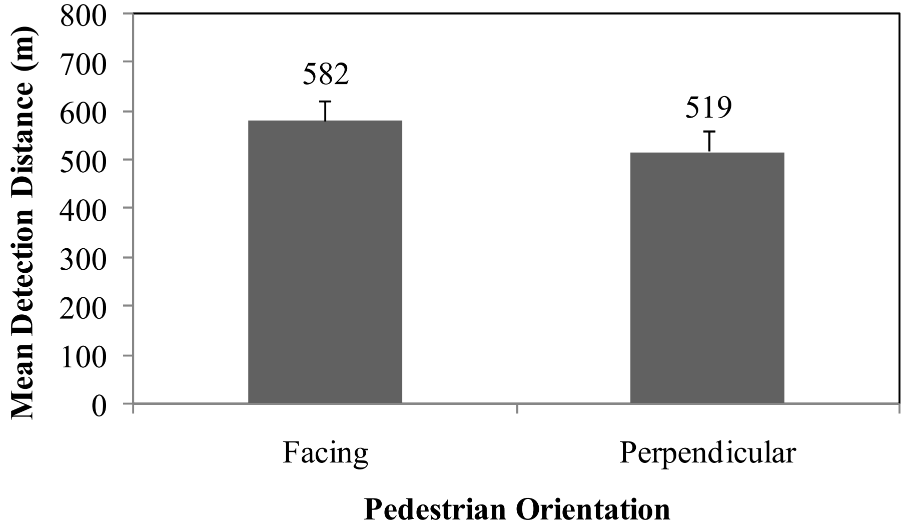


Figure 4. Mean detection distances for pedestrian orientation relative to traffic. Error bars represent standard error of the mean.

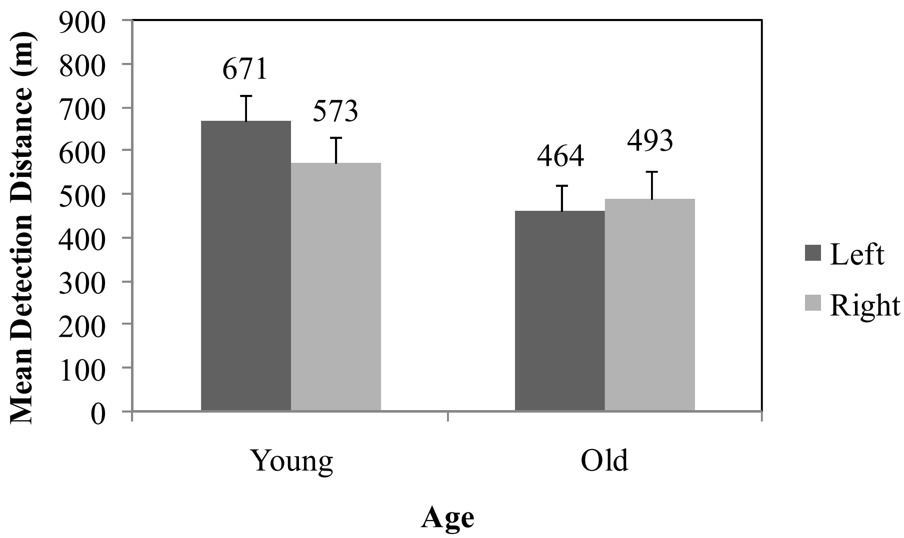


Figure 5. Mean detection distances for the interaction of participant age and pedestrian position. Error bars represent standard error of the mean.

Time of Day by Position

The two-way interaction of time of day by pedestrian position was statistically significant, $F(1,447.1) = 7.2$, $p = .007$. During the day, pedestrians were detected on average 76 m farther when they were standing on the left side of the scene as compared to the right side. At night, the position of the pedestrian relative to the fire truck simulation mattered little (Figure 6).

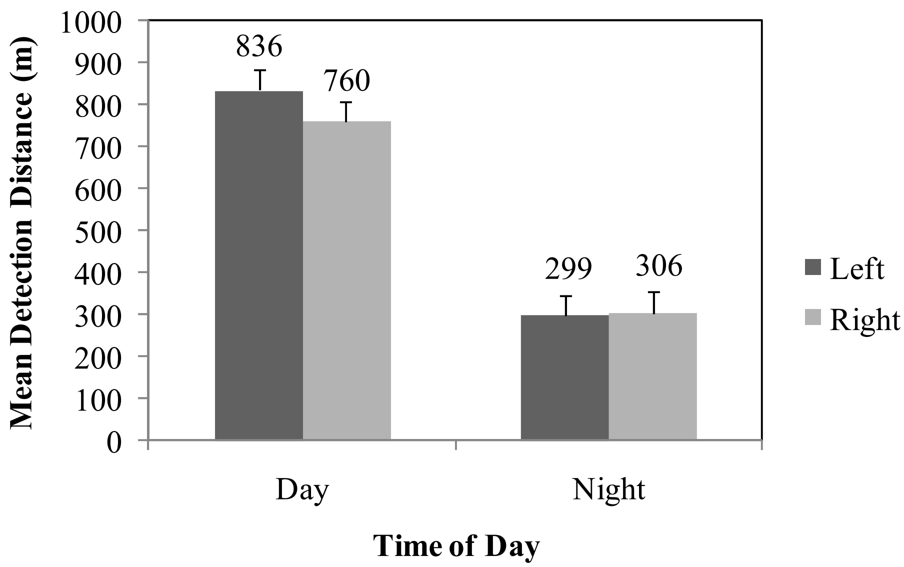


Figure 6. Mean detection distances for the interaction of time of day and pedestrian position. Error bars represent standard error of the mean.

Time of Day by Orientation

The two-way interaction of time of day by pedestrian orientation was statistically significant, $F(1,443.2) = 6.5$, $p = .011$. During the day, pedestrians were detected on average 102 m farther when facing traffic as compared to perpendicular to traffic. At night, the orientation of the pedestrian had little effect on detection distance (Figure 7).

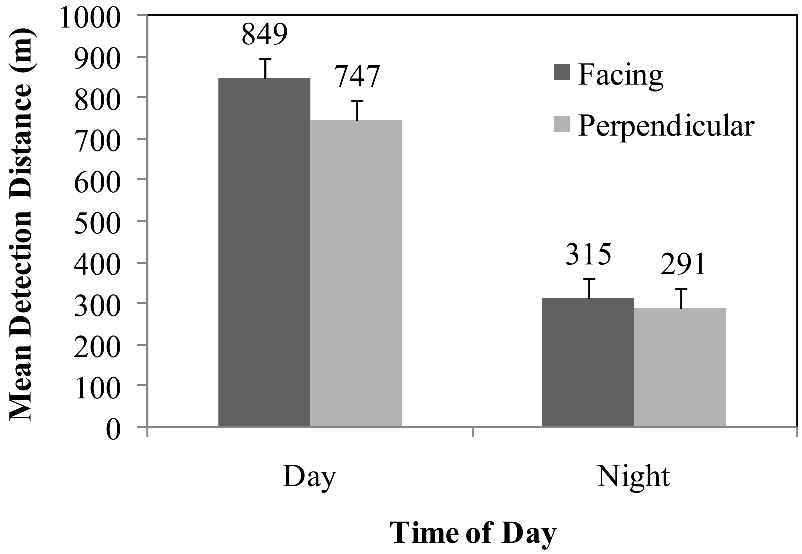


Figure 7. Mean detection distances for the interaction of time of day and pedestrian orientation. Error bars represent standard error of the mean.

Type of Safety Garment by Position

The two-way interaction of type of safety garment by pedestrian position was statistically significant, $F(3,444.0) = 3.1$, $p = .026$. Figure 8 illustrates that with the exception of the ANSI/ISEA-107 vest, pedestrians standing to the left of the fire truck simulation were detected at longer distances than those standing to the right of the fire truck simulation.

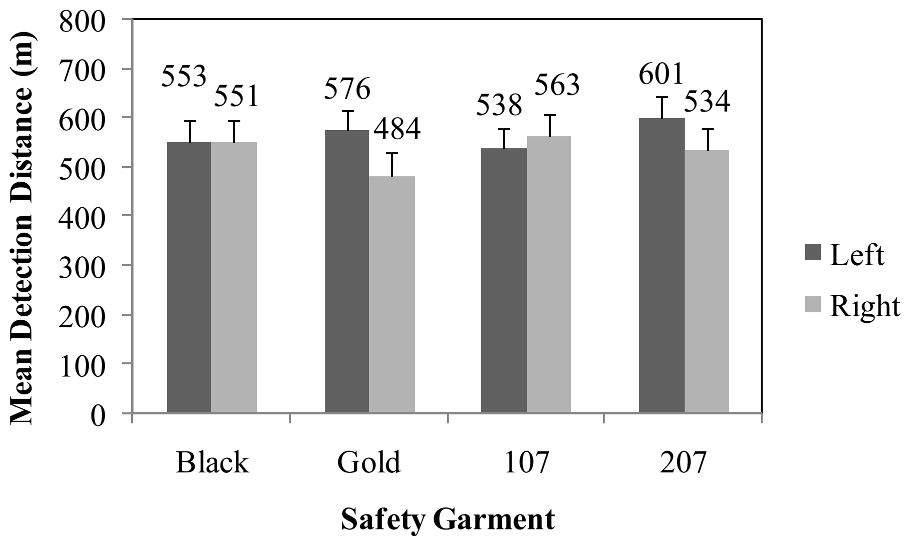


Figure 8. Mean detection distances for the interaction of garment type and pedestrian position. Error bars represent standard error of the mean.

DISCUSSION AND CONCLUSIONS

This study compared different standards of safety garments for conspicuity of first responders in both daytime and nighttime conditions. Significant results indicate that the most important factors related to the conspicuity of first responders are time of day and pedestrian orientation relative to oncoming traffic. Time of day was significant with mean detection distances for all garments in the daytime being longer than the mean detection distances for the nighttime. Pedestrian orientation relative to traffic was significant with mean detection distances for pedestrians facing oncoming traffic being longer than those for pedestrians facing perpendicular to traffic. This effect was likely due to the fact that the drivers could see more of the retroreflective or fluorescent background material when pedestrians were facing traffic. There were several significant two-way interactions all relating to time of day and the pedestrian position and orientation.

The main finding of this study is that in terms of pedestrian conspicuity there is no apparent difference between ANSI/ISEA 107-2004-compliant Class 2 vests, which meet the requirements of the recent FHWA rulemaking (23 CFR part 634), and an ANSI/ISEA 207-2006-compliant vest, or a turnout gear coat that is compliant with NFPA 1971-2007. This finding suggests that turnout gear that is compliant with NFPA 1971-2007, or an ANSI/ISEA 207-2006 compliant vest, provides a similar level of conspicuity as an ANSI/ISEA 107-2004-compliant Class 2 vest. Consequently, the NFPA 1971-2007 turnout gear and ANSI/ISEA 207-2006 Class 2 vest should be considered performance-equivalent relative to compliance with 23 CFR part 634.

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APPENDIX

Day and night views of the simulated fire truck.